ARIZONA DEPARTMENT OF WATER RESOURCES
HYDROLOGY DIVISION

M E M O R A N D U M

To: Salt River Valley Model File

From: Lou Bota, Phil Jahnke, Dale Mason

Date: December 1, 2004

Subject: SRV Model calibration update 1983 - 2002

Purpose

This memo documents recent modifications to and recalibration of the ADWR's Salt River Valley (SRV) groundwater flow model. The modifications are part of a long-term plan to update the existing model. The recalibration was done in cooperation with the East Valley Water Forum, which will use the recalibrated model to simulate a series of water use projection scenarios to test cooperative water management plans among East Valley cities. Presented below is a general overview of the SRV model, a synopsis of modifications to the original model since its initial development, and the results of the 1983 to 2002 model calibration.

Model Background

The SRV model was developed by ADWR to simulate groundwater conditions in the Salt River Valley of the Phoenix Active Management Area (AMA). The model uses the U.S. Geological Survey's MODFLOW groundwater modeling software to simulate quasi three-dimensional flow in the regional aquifer. The model simulates the three major hydrogeologic units in the Salt River Valley using three model layers. Each model layer represents a specific hydrogeologic unit and are in descending order: model layer 1, which simulates the upper most hydrogeologic unit called the Upper Alluvial Unit (UAU), layer 2, which simulates the Middle Alluvial Unit (MAU), and layer 3, which simulates the Lower Alluvial Unit (LAU).

The model grid is 62 miles by 90 miles with model cells that are one mile in width and length. The model grid closely aligns with the township and range grid throughout most of the valley and in many cases a cell overlaps one section of land. The active model domain includes most of the East Salt River Valley (East SRV) and West Salt River Valley (West SRV) sub-basins of the Phoenix AMA and encompasses 2,240 square miles (Figure 1). The model simulates groundwater underflow into and out of the modeled area, groundwater recharge, pumpage, evapotranspiration, and seepage losses to and from the regional aquifer along perennial reaches of the Salt and Gila Rivers. Documentation of the SRV model includes Corkhill and others, 1993; Corell and Corkhill, 1995; Hipke and others, 1996.

Initial Model and Revisions: 1994 to 1997

SRV Model: 1994

The initial SRV model was developed in the late 1980s and early 1990s and is documented in Modeling Reports No. 6, (Corkhill and others, 1993) and No. 8 (Corell and Corkhill, 1994). Modeling Report No. 6 presents an overview of the geologic and hydrologic characteristics of the Salt River Valley and contains a detailed analysis of groundwater pumpage, recharge, evapotranspiration and groundwater underflow for the period 1983 to 1989. The data assembled for Report Number 6 were used to develop a numerical groundwater flow model using the U.S. Geologic Survey's modeling software MODFLOW. Modeling Report Number 8 documents construction of the numerical model, its calibration and sensitivity analysis and recommendations for future model updates. Model documentation also included extensive paper files and electronic database containing data used to develop model data sets.

The initial model simulated a predevelopment, or steady-state, period of circa 1900 and a developed, or transient, period of 1983 to 1988. The model was run using MODFLOW-88 and utilized seven modules, or packages, available at the time. The packages used in the initial model were: 1) the Basic (BAS) Package, 2) the Block-Centered Flow (BCF) Package, 3) the Well (WEL) Package, 4) the Recharge (RCH) Package, 5) the River (RIV) Package, 6) the Evapotranspiration (ET) Package, and 7) a numerical solver.

The BCF package used in the initial model, BCF1, did not include a cell rewetting capability. Succeeding versions of the BCF package have incorporated the ability to allow cells that have gone dry at one point during a simulation, and become inactive cells, to rewet and become active again. The rewetting capability allows cells to remain active as water levels change through time, thus allowing more realistic long-term simulation of regional hydrologic systems that have experienced large water level fluctuations through time.

The Well package was used to simulate pumpage from the regional aquifer and groundwater underflow at some boundaries to the model. Estimates of groundwater pumpage reported in Modeling Report 6 were used to develop the initial simulated withdrawal volumes during the developed period. Groundwater underflow at some model boundaries was specified as constant fluxes using the Well Package. Groundwater flux across other model boundaries was simulated using constant head cells. The Recharge Package was used to simulate the areal distribution of recharge within the active model domain. Simulated recharge included natural (mountain-front and stream infiltration from flood flows) recharge, agricultural and urban irrigation sources, canal seepage, and artificial lake seepage. A lag factor of 10 feet per year was used to delay the arrival of incidental recharge from agricultural irrigation to account for travel times of irrigation recharge between the land surface and the water table.

The River package was used to simulate the ordinary day-to-day exchange of water between the groundwater system along perennial reaches of the Salt and Gila Rivers. The active part of the River package was downstream of the 91st Ave. wastewater treatment plant where effluent discharge has created perennial flow in the river. Flood flow events along the Salt and Gila Rivers were not simulated with the River package; estimated recharge due to large flood events was applied using the Recharge package. The ET package simulated the effects of transpiration from riparian vegetation and direct evaporation of water from the land surface.

For a complete description of the MODFLOW packages the reader is referred to McDonald and Harbaugh (1988). For a detailed description of the construction of the SRV Model the reader is referred to Corkhill and others (1993) and Corell and Corkhill (1994).

Current Trends Analysis: 1996

Modeling Report No. 11, called the Current Trends Alternatives (CTA), extended the SRV model transient calibration three years, making the total calibration period from 1983 to 1991, and projected groundwater conditions out to 2025. The ADWR assembled water use and supply projections in 1993 and 1994 from the principal water users and providers in the Phoenix AMA. The water users and providers furnished the ADWR with their best estimate of the amount and source of water that they would supply customers out to 2025, which is the date that the AMA is mandated to reach its goal of Safe Yield.

Other than updating pumpage and recharge values through 1991, the only modification to the numerical model was the incorporation of the rewetting capacity in the BCF package. As discussed previously, the rewetting capacity allows cells that have gone dry during an earlier point in a simulation to rewet if water levels rise above the bottom of a dry cell at a later point in the simulation. This allows the model to more accurately simulate groundwater flow in areas that have experienced large water level declines that dewatered cells, followed by water level recoveries that resaturate cells. The rewetting capacity was also useful to accurately simulate the impact of artificial recharge facilities where mounding of recharge may cause water levels to rise into an overlying layer that was previously dry. The rewetting capability was incorporated in all three layers of the SRV model. For a detailed discussion of the CTA modeling assumptions, estimates of future water supply and demand, and the results of the model simulation, please see Hipke and other (1996).

Model Revision in 2004

A number of modifications have been made to the initial 1994 SRV model and the 1996 CTA update. They include updating the model to run using MODFLOW-2000, the addition of new MODFLOW packages, and increasing the model calibration period. The changes are detailed below.

Model calibration 1983 – 2002

The most recent update of the SRV model extends of the model calibration period from 1983 to 2002. The extended calibration period covers twenty years of development, a period during which ADWR conducted four sets of water level inventories in Phoenix AMA (1983, 1991, 1997, 2002). The new field data reflect the effects of changing pumping and recharge conditions on the groundwater system. Pumpage and recharge data sets were updated through 2002 to take advantage of the latest water level sweep.

Figures 1 and 2 show water level changes measured at wells between 1983 and 2002, and 1997 and 2002, respectively. The maps show broad areas of East SRV sub-basin where water levels generally rose during most of the 1980's and 1990's. However, the more recent data from 1997 to 2002 indicate the trend in rising water levels has diminished significantly in the last 5 to 6 years. The long-term rises are mainly attributed to an overall decline in groundwater pumping from the pumping levels of the 1950's through the early 1980's, and the introduction of CAP water for municipal and agricultural use. Significant flood recharge on the Salt and Gila River systems and the introduction of artificial recharge at the Granite Reef Underground Storage Project (GRUSP) site have also contributed to the water level rises. The recent water level change data (Figure 2) indicate that the groundwater system has generally adjusted to the major changes in pumping and recharge that occurred during the 1980's and early 1990, and once again reflect the effects of long-term groundwater overdraft in many parts of the AMA. The recent data also reflects the effect of the current drought, which has reduced surface water supplies and in some areas has resulted in increased groundwater pumpage.

The complexity of groundwater system has increased due to the physical transformations caused by groundwater pumping. One result of excessive groundwater pumping is that large areas of land subsidence have been identified within the study area. Figure 3 shows a large area of land subsidence (maximum subsidence ~ 23 cm from 1992 to 2000) in the East SRV sub-basin, near Apache Junction, where historic groundwater pumping has depleted aquifer storage and contributed to the permanent compaction of the aquifer system.

Conversion to MODFLOW-2000

The SRV model was converted to run using MODFLOW-2000 and a new feature of Basic (BAS6) package, the Head Observation (HOB) process, was implemented for the model simulation. The HOB process provides several important capabilities for model calibration, which include: 1) calculating model-simulated heads at the location of observed heads by interpolation using simulated heads from cells surrounding the observed heads, 2) calculates composite heads for wells that are screened across two or more model layers, and 3) provides a statistical analysis of observed vs. model-simulated heads.

The HOB process also allows observed heads to be assigned a weighting factor, which permits observed heads with more accurate elevations to be assigned more weight than observed heads with less accurate elevations. This allows the more accurate observation points (heads) to have more influence than less accurate observation points on the statistical results generated by the HOB process. The statistical results generated by the observation process describe head residuals (observed heads minus simulated heads) and how they compare to expected normally distributed results. The HOB process also creates a number of files that contain model results that can be used for graphical comparisons between the observed and simulated heads. The statistical measures generated by the observation process provide a quantitative measure of a model simulation, thus helping to remove subjective judgment from the model calibration process. For a detailed description of MODFLOW-2000 and the Head Observation process the reader is referred to Harbaugh and others (2000) and Hill and others (2000). A detailed description of the weighting process is included below in the model calibration results section.

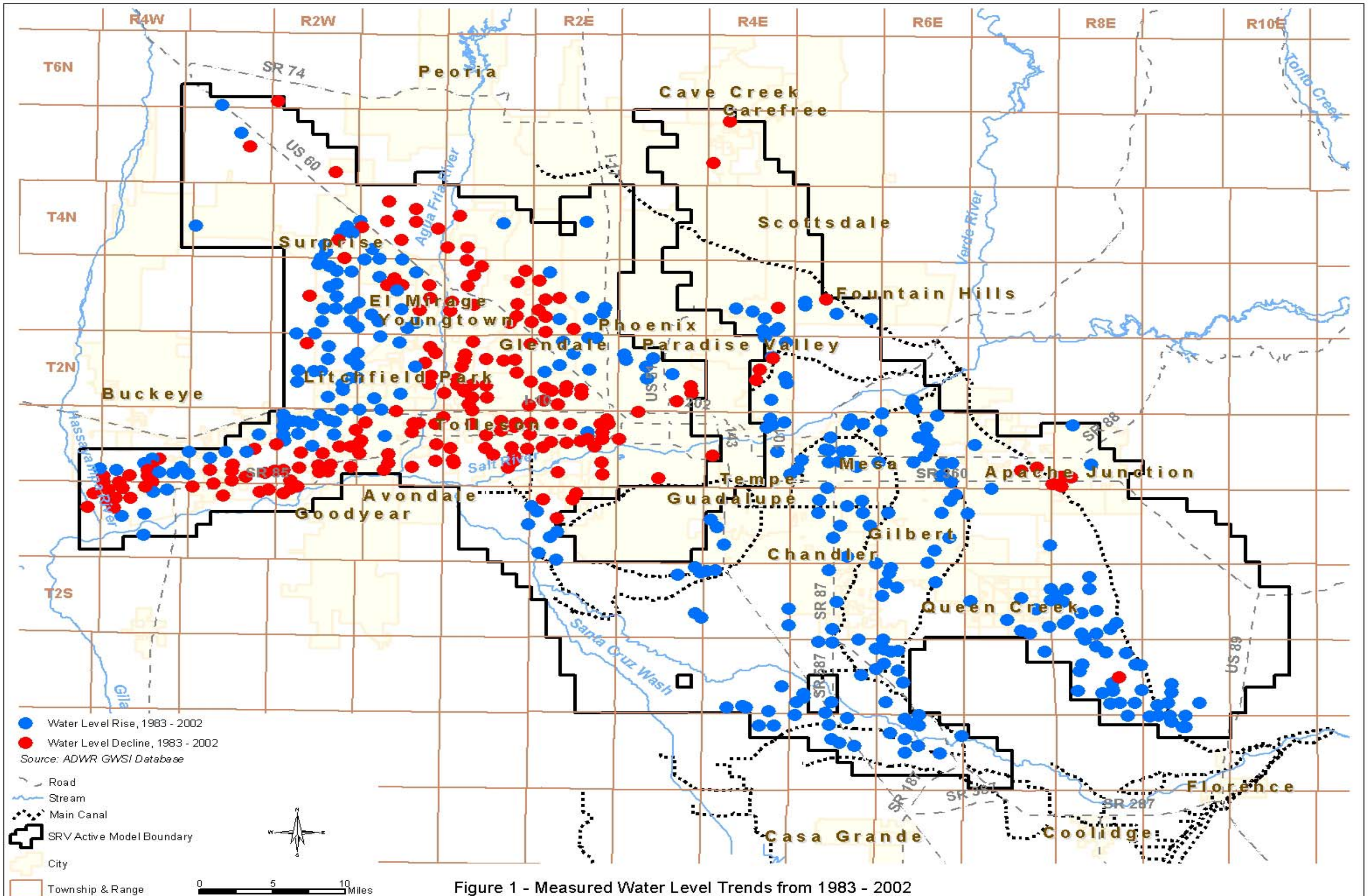


Figure 1 - Measured Water Level Trends from 1983 - 2002

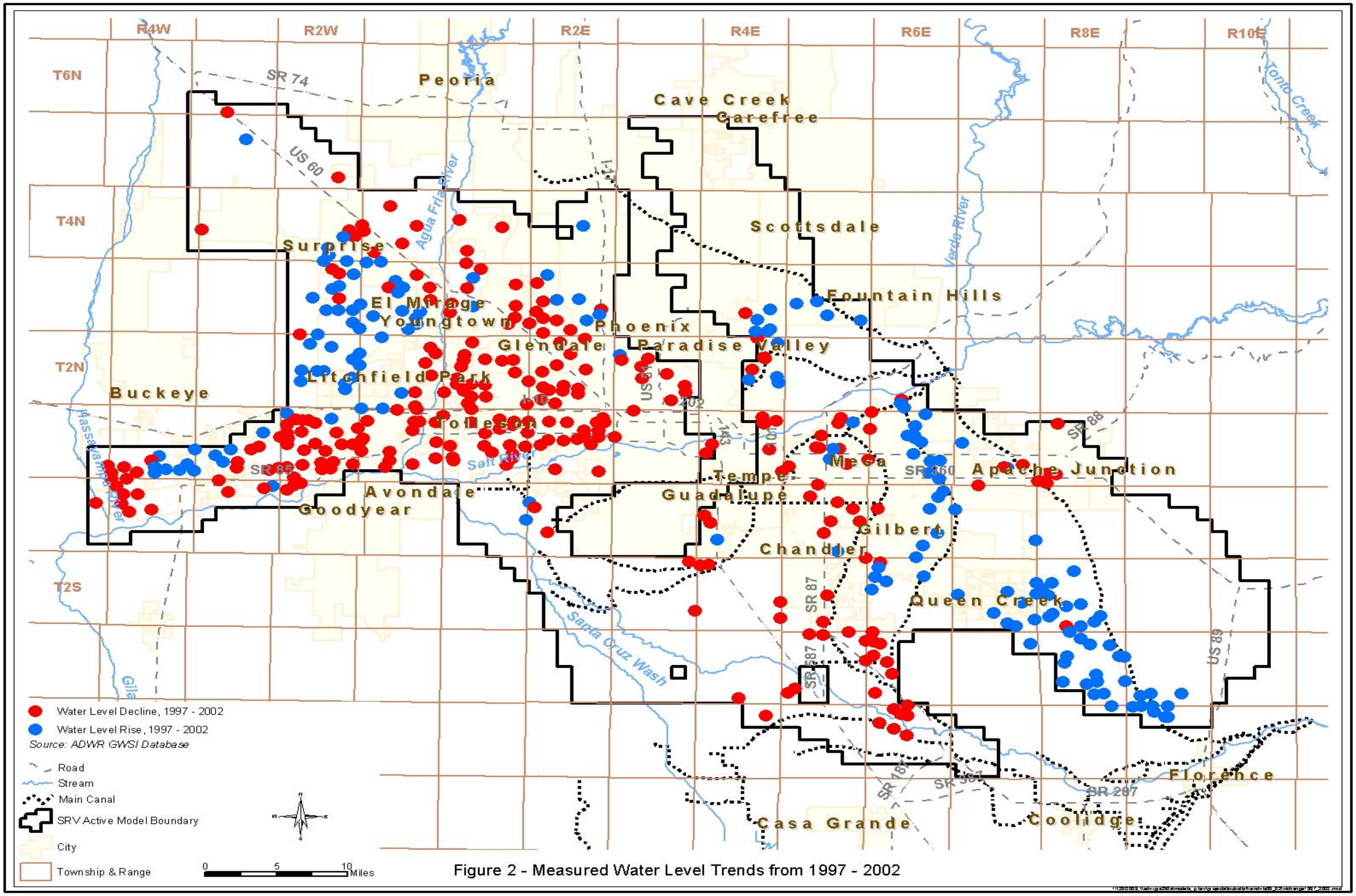


Figure 2 - Measured Water Level Trends from 1997 - 2002

Stream-Flow Routing Package

A major change from the original SRV model has been the substitution of the Stream-Flow Routing (STR) Package for the River Package. The number of miles of river channels that are simulated by the model has been greatly expanded by adding the Agua Fria, Santa Cruz, and Hassayampa Rivers, and the Buckeye Irrigation Canal to the STR package. In addition, the Gila and Salt Rivers have been expanded to include their entire lengths within the model domain. This is particularly important because the non-perennial reaches of the river channels can now act as drains in the presence of high water tables. The River Package was capable of simulating infiltration and groundwater discharge, however; it wasn't implemented in non-perennial reaches of the river system. The Recharge Package is still used to simulate normal stream flow infiltration and flood flows along the Salt and Gila Rivers and.

Discharges from the 23rd and 91st Avenue Waste Water Treatment Plants into the Salt River were assigned using the Recharge package in the initial SRV model. The model update uses the Stream-Flow Routing (STR) package to simulate releases from the wastewater treatment plants as tributary inflow into the Salt River channel. The Buckeye Irrigation Canal, located just north of the Gila River, is simulated as a diversion in the STR package. The canal presently diverts all of the flow in the Gila River at the Buckeye heading, which is located a few miles west (downstream) of the 91st Avenue Waste Water Treatment Plant. The Buckeye Canal is unlined and seepage through its bottom and sides is a significant source of recharge.

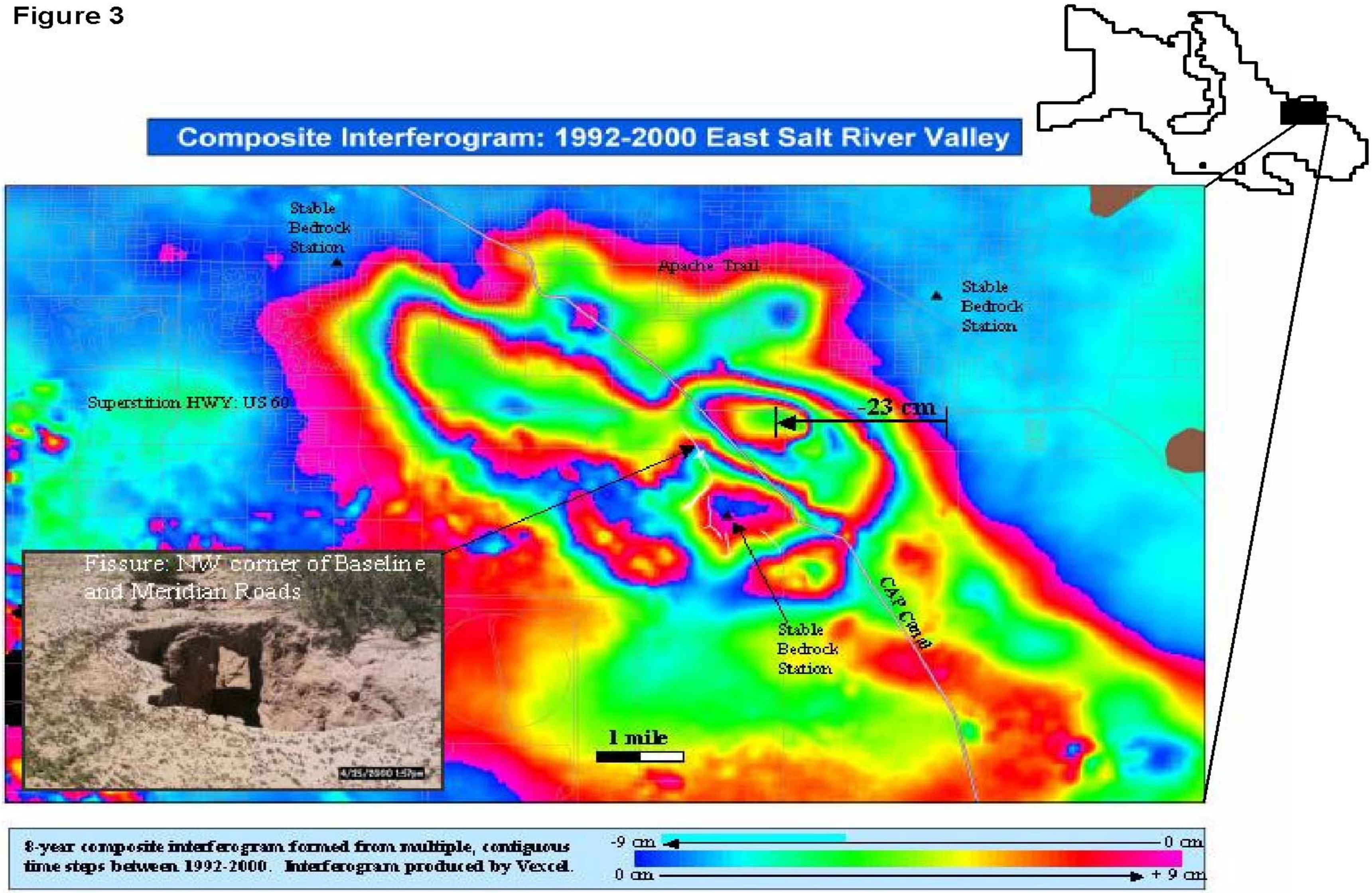
Distribution of Historic Salt and Gila River Channel Recharge

Floods on the Salt and Gila Rivers have been important recharge events in the model domain. Recharge from flood events is now distributed non-linearly from Granite Reef Dam westward to the 23rd Avenue Waste Water Treatment Plant on the Salt River and along the Gila River downstream from Ashurst-Haden Dam. Simulated recharge volumes are based on the reported volume of water released at Granite Reef Dam and Ashurst-Hayden Dam. The majority of floodwater infiltration along the Salt River channel is distributed in the far East Valley where the water table is generally deeper and hydraulic conductivities in the middle aquifer are much higher than they are in the West SRV sub-basin. Because floods and spills at Granite Reef and Ashurst-Hayden Dams are short-term events (days or weeks) and model stress periods are one year in duration, recharge from flood events is annualized and simulated using the Recharge package.

Flood recharge is zero during most years; so simulated surface-water flows on the Salt and Gila Rivers are set to zero in the Stream-Flow Routing package. Major flood recharge events were simulated during the years 1983 through 1988, 1992 and 1993, 1995, and 1998 along the Salt River channel, and in 1983, 1992 and 1993, and 1995 along the Gila River. Flood-flow infiltration along the Gila River was adjusted downward about 10% to 13% from previous estimates in the upstream portion (Township 4 South) of the channel during the recalibration. This was done because simulated water levels in this area were too high.

Simulated flows on the Gila River caused by groundwater discharging into the channel generally occur only during flood years when the water table rose significantly for short periods due to the

Figure 3



8-year composite interferogram formed from multiple, contiguous time steps between 1992-2000. Interferogram produced by Vexcel.

D:\Documents\water dot az dot gov\main site\02072005Dale\srvupdate83-02.doc flood recharge events. These discharges only occurred in a limited number of river cells along the upper portions of the Gila River, most river cells remain dry during the simulation. Currently base flow conditions only occur along a stretch of the Gila River downstream from the confluence with the Santa Cruz River

Long-term estimates of recharge in the Salt River channel have been significantly lowered from 97,000 acre-feet per year to around 54,000 acre-feet per year. This was done after additional long-term spill data for the Salt River, going back to 1912, were included in the analysis of flood recharge.

Extended Calibration with Additional Recharge Components

As mentioned earlier, the model calibration period has been extended through 2002 (from 1992) with the addition of updated pumpage and recharge data. Pumpage was updated through 2002 using data from the ADWR Registry of Groundwater Rights (ROGR) database. Updates to the recharge package include new estimates of existing recharge sources and the addition of several new recharge sources. Updates of estimated recharge along the Salt and Gila Rivers were discussed previously; annual recharge along Queen Creek was also increased. New recharge sources include recharge distributed along Indian Bend Wash, non-effluent recharge sites along the Agua Fria channel, and new managed groundwater recharge sites that came on-line during the 1990s.

Aquifer Parameters Near Salt River

In conjunction with changing the flood recharge distribution; the hydraulic conductivities of model cells in the Middle Alluvial Unit under and near the upper reaches of the Salt River channel were changed to match those of the Upper Alluvial Unit. Hydrogeologic studies from the Salt River Project's Granite Reef Underground Storage Project (GRUSP) indicate that clay layers previously thought to exist along the upper Salt River are missing or small in extent. Increasing the layer 2 hydraulic conductivities resulted in an improved calibration in the area.

Modification of Hydraulic Conductivity Data

The original hydraulic parameters of the SRV model that are described in modeling reports 6, 8 and 11 were used for initial model inputs for the extended calibration period. However, in some areas, new information from recent aquifer tests and hydrologic studies were used to modify existing hydraulic conductivity values. New hydraulic conductivity data from ground water modeling studies by Southwest Groundwater Consultants (2000, 2001) and Clear Creek Associates (2002) for the City of Chandler were incorporated into the SRV model. The results of the modifications to the SRV model hydraulic conductivities, including the Chandler data, are compared to SRV model output that does not include the Chandler model data in Figure 4. The results indicate that the inclusion of the Chandler hydraulic conductivity data had little impact on overall model results except in the immediate Chandler area.

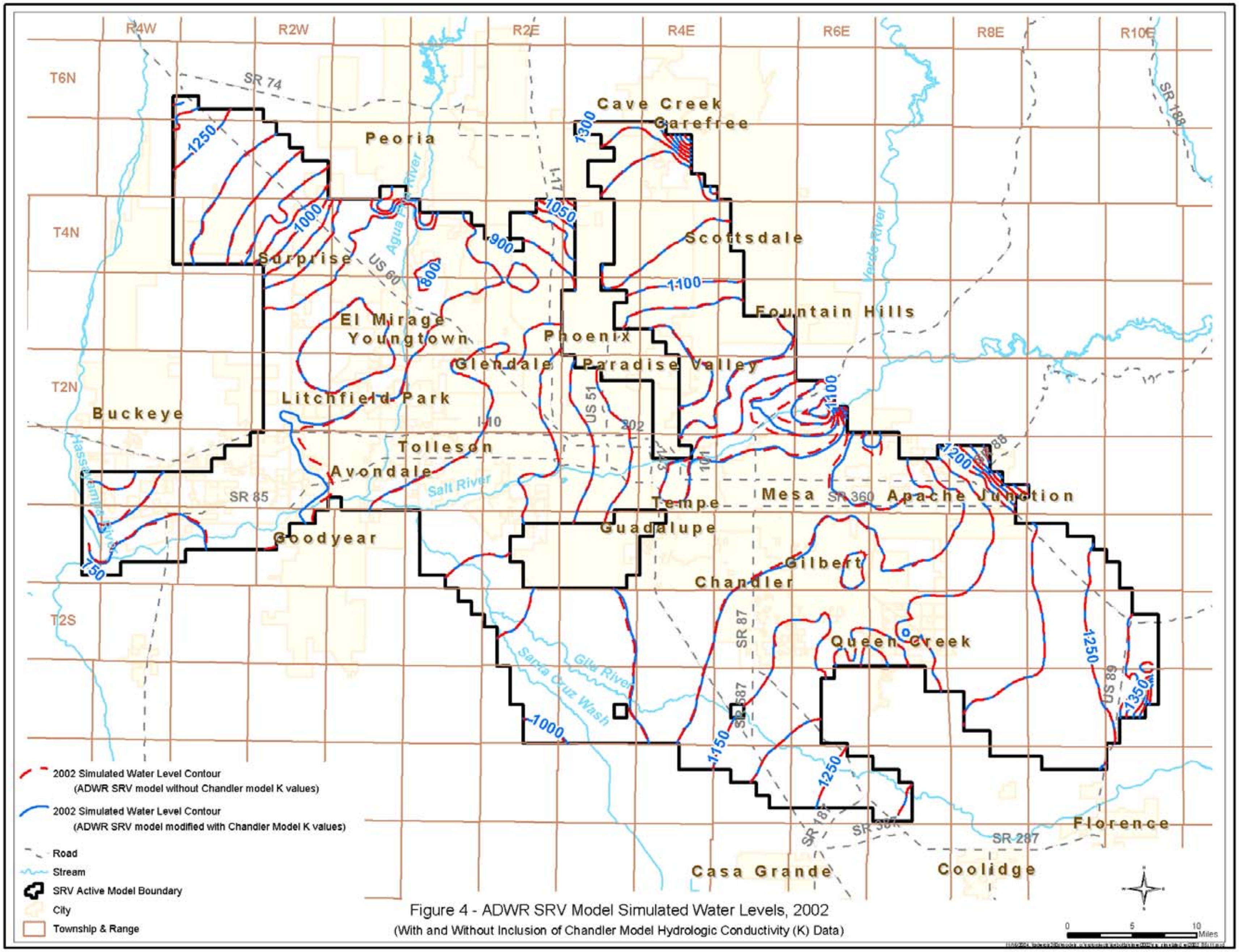


Figure 4 - ADWR SRV Model Simulated Water Levels, 2002
(With and Without Inclusion of Chandler Model Hydrologic Conductivity (K) Data)

1983 – 2002 Model Calibration Results

Updating the SRV groundwater flow model has improved the model calibration results in several areas of the model. The results of the 1983 to 2003 model calibration are described below and include both qualitative and quantitative results. Qualitative results include comparisons of 2002 observed water level contours vs. simulated water level contours (Figure 5), a map showing the distribution of head residuals (Figure 6), and selected hydrographs that compare observed and simulated water levels through time (Figure 9). Quantitative results include summary statistics that describe the average model error using weighted head residuals (simulated weighted head minus observed weighted head) (Table 1), frequency distributions of the weighted residuals (Table 2 and Figure 7), and water budget information (Tables 3 and 4).

The Hydraulic-Head Observation (HOB) option of MODFLOW-2000 was utilized in this study to compare simulated heads with observed water levels (heads). The HOB option provided two important functions, 1) it allows water level observations that are deemed more accurate to be assigned more significance, or weight, than observations that are believed to be less accurate when calculating the simulations summary statistics, and 2) it calculates simulated heads at the location of observed heads.

The weighting method suggested by Hill (1998), which evaluates the accuracy of an observed water level was utilized to determine the weighting factor used in the model update. Most site elevations in the ADWR Ground Water Site Inventory (GWSI) database were determined in the field from U.S. Geological Survey (USGS) 7.5-minute quadrangle maps. Each site in the GWSI is assigned an altitude accuracy of one-half the contour interval of the map used to determine a site elevation. The altitude accuracy is based on vertical accuracy standards for USGS maps, which states that, “not more than ten percent of the elevations tested shall be in error more than one-half the contour interval” (U.S. Geological Survey, 1980). Typical altitude accuracies for well elevations determined off contour maps range from 5 to 20 feet. A small percentage of wellhead elevations were determined by conventional instrument or precision GPS surveys. Wellhead elevations determined by instrument or GPS surveys are very accurate, which is reflected in altitude accuracy values that are typically one foot or less.

The altitude accuracy field in the GWSI can be used to determine the measurement error for well elevations, and by extension, the error of water level measurements from a well. The USGS altitude accuracy standard establishes a 90% confidence interval that water level elevations in the GWSI are plus or minus a well’s assigned altitude accuracy. The confidence interval can be used to calculate the estimated standard deviation of the water level elevation error. Assuming a normal distribution, the 90% confidence interval is constructed by adding plus or minus 1.65 times the standard deviation of the measurement error. The 1.65 can be looked up in any table that lists the cumulative probabilities for a standardized normal distribution.

The formula for calculating the estimated standard deviation of the water level elevation error is:

$$1.65 \text{ X SD} = \text{Altitude Accuracy}$$

where: SD = estimated standard deviation

An example using an altitude accuracy of 10 feet (map contour interval = 20 feet) yields an estimated water level measurement error of ±6.06 feet.

$$1.65 \times SD = 10 \text{ feet};$$
$$SD = 10/1.65$$
$$SD = 6.06 \text{ feet}$$

The MODFLOW-2000 Head Observation process can use the standard deviation of the measurement error to calculate a weighting factor for observation heads (Harbaugh and others, 2000; Hill and others, 2000). The results of the weighting procedure is that observation points with less precise well head elevations measurements (greater measurement error) are assigned less weight than observation points with more precise well head elevations measurements (less measurement error) when the HOB process calculates the summary statistics that describe the average error for a simulation. For a more detailed discussion of observation weighting, please refer to Chapter 6 in Hill (1998).

Observation heads rarely coincide with cell center locations, so to provide accurate comparisons between simulated and observed data the HOB package uses geometric interpolation to calculate a simulated head at the location of an observed head. The methods used to calculate the interpolated heads are discussed in Hill and others (2000). The HOB option results include the observed heads and their associated interpolated simulated heads, and the difference (residual) between the heads. If the weighting option is used the observed and simulated heads are multiplied by the assigned weighting factor and the residual is calculated as described below. The weighted residuals from the HOB package were used in the statistical and frequency distribution analysis. The weighted residual (difference) between the interpolated simulated head and observed water level were determined using the formula:

$$R_i = H_s - H_o$$

where:

R_i = the residual
H_s = the interpolated model simulated head value at the location where H_i was observed
H_o = the observed head at point *i*

Water Level Results:

Figure 5 shows the 2002 observed water level contours vs. the final simulated water level contours. Comparison of the observed and simulated contours indicates that the model was generally able to replicate the regional pattern of groundwater flow. Summary statistics that compare final simulated and observed water levels include model-wide weighted residuals, layer specific weighted residuals and sub-basin specific weighted residuals are presented in Table 1

The mean error (ME), root mean square error (RMSE), and mean absolute error (MAE) of the weighted residuals are used to describe the average error in a model. The ME is simply the average of the residuals and the MAE is the average of the absolute value of the residuals. The RMSE describes the spread or variability the weighted residuals, the larger the variability of the residual data the larger the resulting RMSE value.

The ME and RMSE of weighted residual for the entire SRV model are –2.4 feet and 15.8 feet, respectively. The ME's negative value indicates that, overall, the model tends to under-simulate water levels. The MAE of the weighted residuals is 11.4 feet, which means that the average simulated head is about ± 11 feet from an observed head. The spatial distribution of model error is presented in Figure 6, which shows the location and approximate magnitude of the weighted head residuals. The summary statistics in Table 1 indicate that the model calibration is better in the East SRV sub-basin than in the West SRV sub-basin and that the model tends to under simulate heads in the West SRV sub-basin and over simulate heads in the East SRV sub-basin. The ME, RMSE and MAE values for the East SRV sub-basin are, 3.4 feet, 11.3 feet and 8.4 feet, respectively. In the West SRV sub-basin the ME, RMSE and MAE values are –6.8 feet, 17.2 feet and 13.7 feet, respectively. The pattern of mostly negative residuals in the WSRV sub-basin (ME = -6.8 feet) and generally positive residual in the ESRV sub-basin (ME = +3.4 feet) can be observed in residual map (Figure 6) and in the frequency distributions of the weighted residuals (Table 2 and Figure 7).

Another measure of average model error is the ratio between the RMSE and the total head loss of the modeled system, which is called the normalized RMSE. If the normalized RMSE value, expresses as a percentage, is small, less than 10% is the usually the acceptable value, then the model error is only a small part of the overall model response (Anderson and Woessner, 1992). The normalized RMSE ratio for the 1983 to 2002 calibration is 2.03%, based on a total head loss across the SRV model of 780 feet and an RMSE of 15.8 feet. The normalized RMSE ratio was determined to be sufficiently small and therefore, the average model error for the simulation was judged to be acceptable.

The statistical measures calculated by MODFLOW-2000 from the weighted head residuals include the correlation coefficient and the results of a run test. The correlation coefficient is a measure that describes the match between the simulated and observed heads and can be presented as a value and displayed graphically as a scatter plot. The closer the correlation value is to 1.0, the greater the correlation between observed and simulated heads, or the closer an observed head is to a simulated head. Hill (1998) recommends that the correlation coefficient be greater that 0.90. The correlation coefficient of the simulated and observed heads for the updated SRV model is 0.954, and a scatter plot of the weighted simulated heads vs. the weighted observed heads is presented in Figure 8a. As previously discussed, MODFLOW-2000 uses head residuals to calculate several statistical measures that describe the simulation results. The observed heads used to calculate the residuals can be weighted using the HOB package, which allows more accurate observed heads to have more influence on the statistical results than less accurate observed heads. Less accurate observed heads are usually assigned small weighting factors, which in turn, produce small values for the associated observed and simulated heads. The results of small weighting factors can be observed in Figures 8a and 8b, where weighted observed and weighted simulated heads of less than 100 feet occur.

The run test is a summary statistic that tests the weighted residuals for randomness. Ideally, residuals plotted on a graph should show no discernable pattern. If a pattern is observable than the residuals are biased, which can indicate a problem with the model calibration (Hill, 1998). The results of the run test for the SRV weighted residuals indicate that the residuals are not random. A spatial bias can be observed in the distribution of weighted residuals in both Figures 6 and 8b.

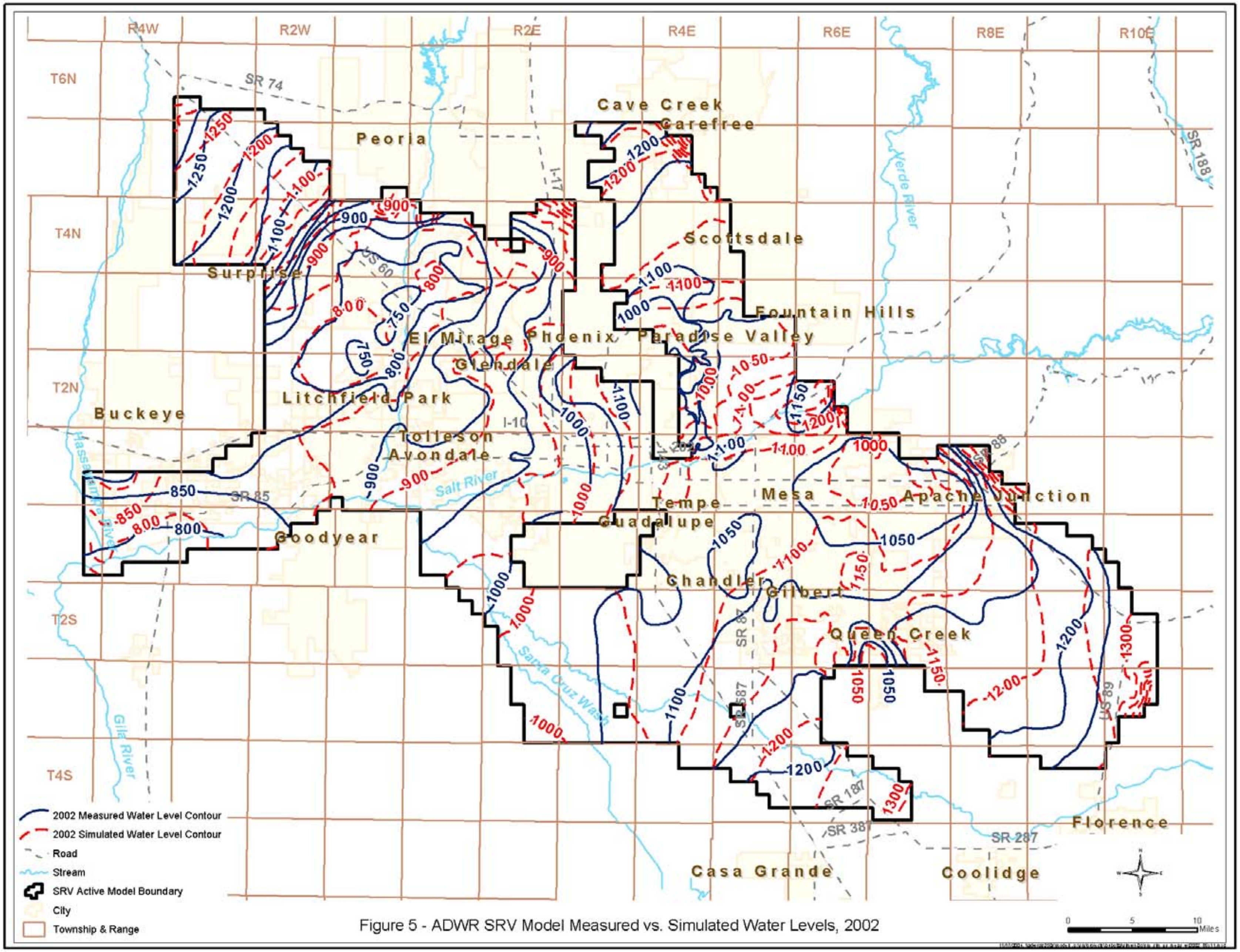


Figure 5 - ADWR SRV Model Measured vs. Simulated Water Levels, 2002

Table 1. Statistical summary of the weighted head residuals in 2002, SRV model (values are in feet).

	Model-Wide	West SRV	East SRV	Layer 1	Layer 2	Layer 3	Multi-Layer
Mean	-2.3	-6.9	3.8	-10.5	2.4	3.6	-2.7
Stan. Dev.	16.0	17.3	11.5	15.7	17.8	14.0	14.6
Absolute Mean	11.5	13.8	8.5	14.4	12.4	11.1	10.6
Maximum	93	68	93	34	68	25	93
Minimum	-72	-72	-36	-72	-43	-52	-68
Count	834	477	357	121	172	62	479

Weighted head residual = weighted simulated head – weighted observed head

Table 2. Frequency distribution of the absolute value of the weighted residuals in 2002, SRV model.

Absolute Ranges (ft)	Model-Wide		West SRV sub-basin		East SRV sub-basin	
	Frequency	Cumulative Percent	Frequency	Cumulative Percent	Frequency	Cumulative Percent
0 to 10	476	57.07%	228	47.80%	248	69.47%
10 to 20	219	83.33%	137	76.52%	82	92.44%
20 to 30	83	93.29%	62	89.52%	21	98.32%
30 to 40	31	97.00%	27	95.18%	4	99.44%
40 to 50	12	98.44%	11	97.48%	1	99.72%
50 to 60	9	99.52%	9	99.37%	0	99.72%
60 to 70	1	99.64%	1	99.58%	0	99.72%
70 to 80	2	99.88%	2	100.00%	0	99.72%
80 to 90	1	100.00%	0	100.00%	1	100.00%

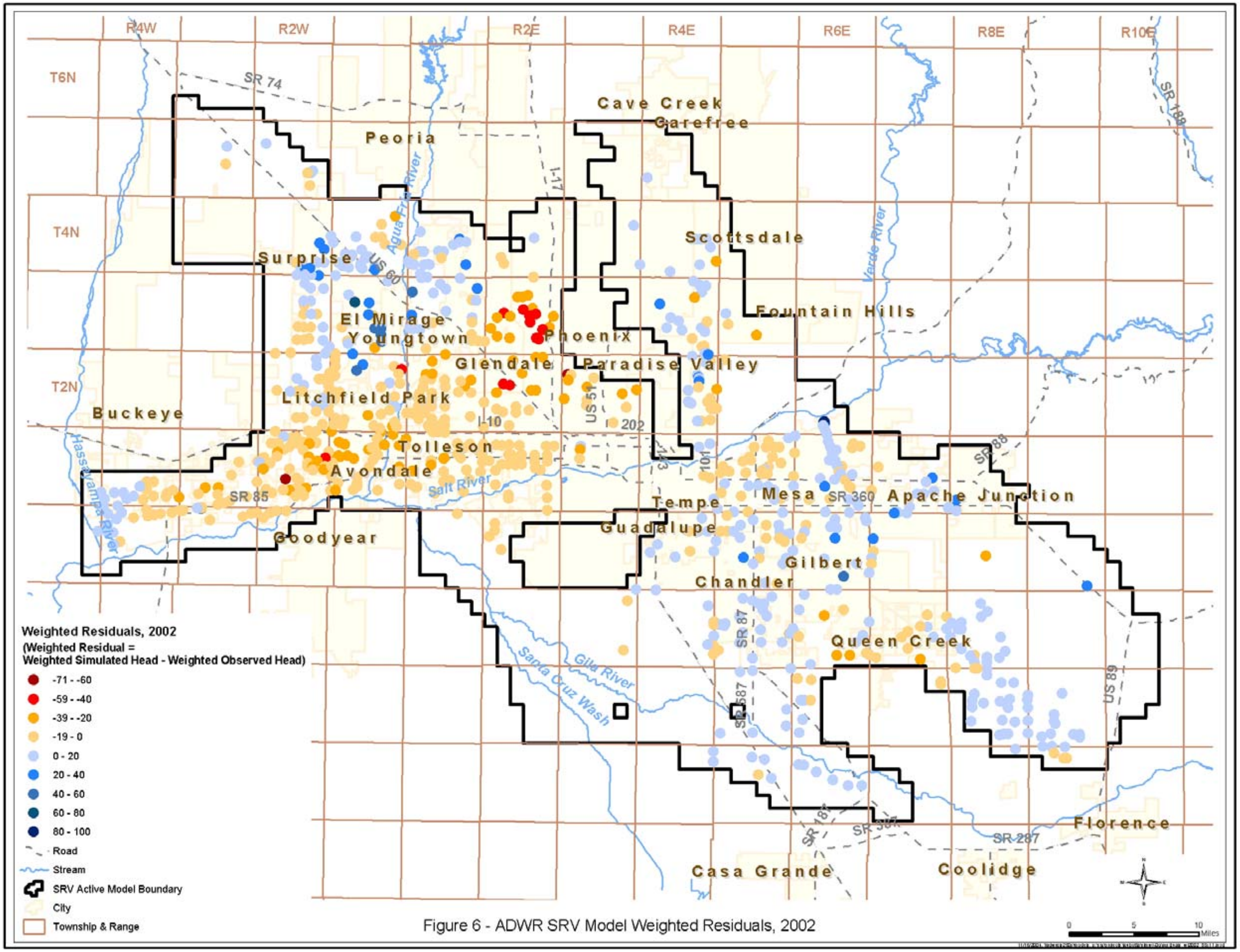


Figure 6 - ADWR SRV Model Weighted Residuals, 2002

Figure 7. Frequency histograms of weighted residuals for a) model-wide, b) West SRV sub-basin, and c) East SRV sub-basin.

Figure 7a.

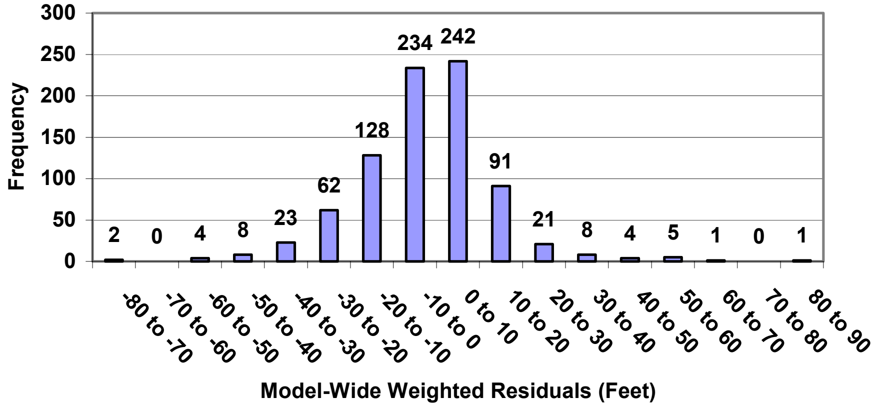


Figure 7b.

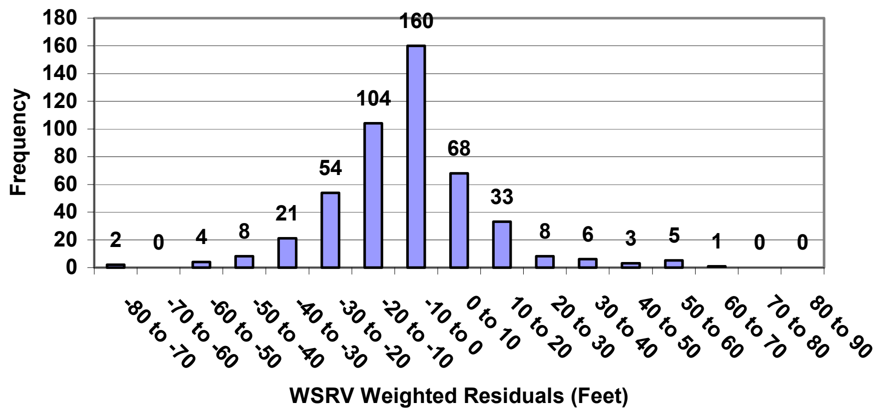


Figure 7c.

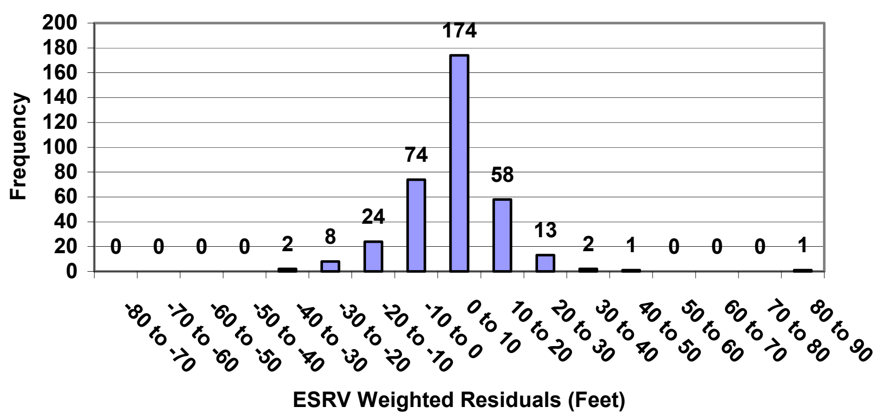


Figure 8a. Scatter plot of model-wide weighted simulated heads vs. weighted observed heads

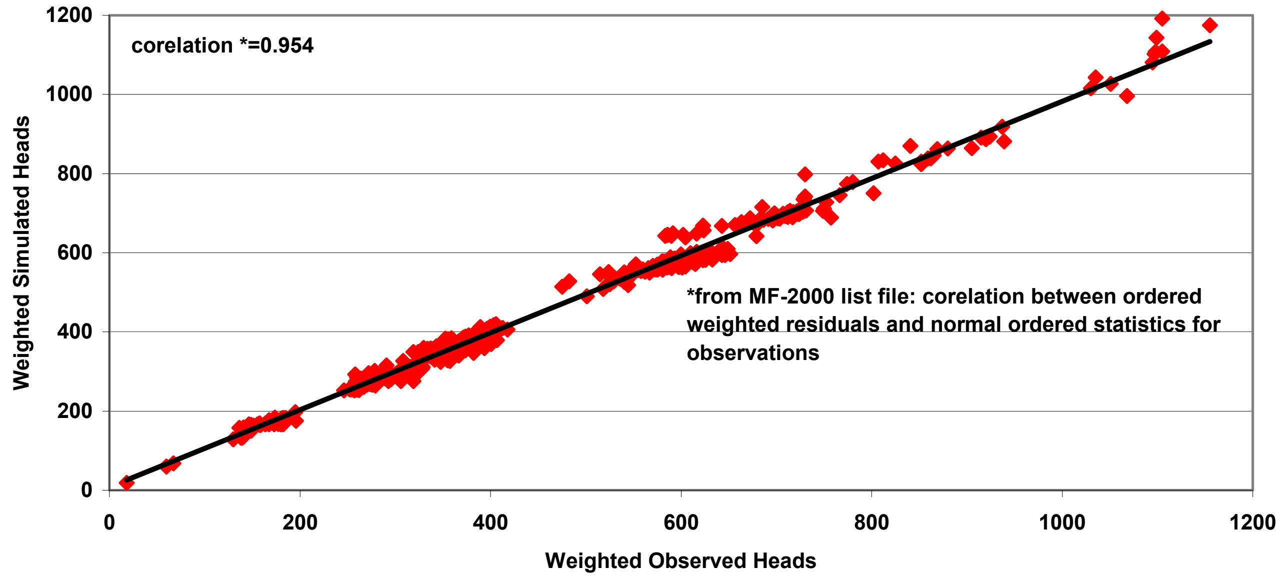
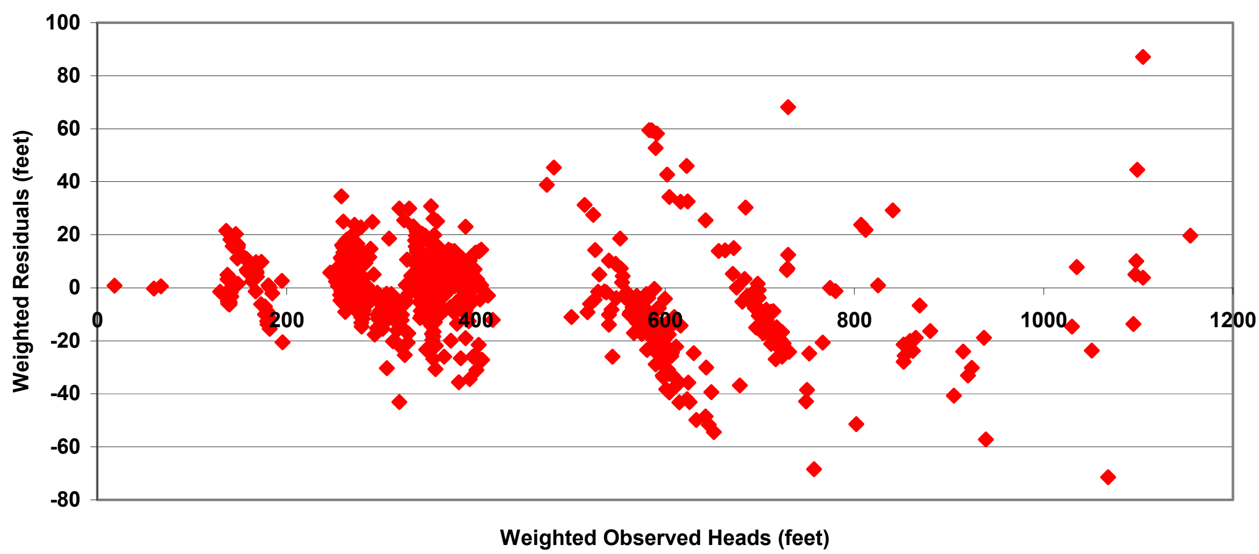
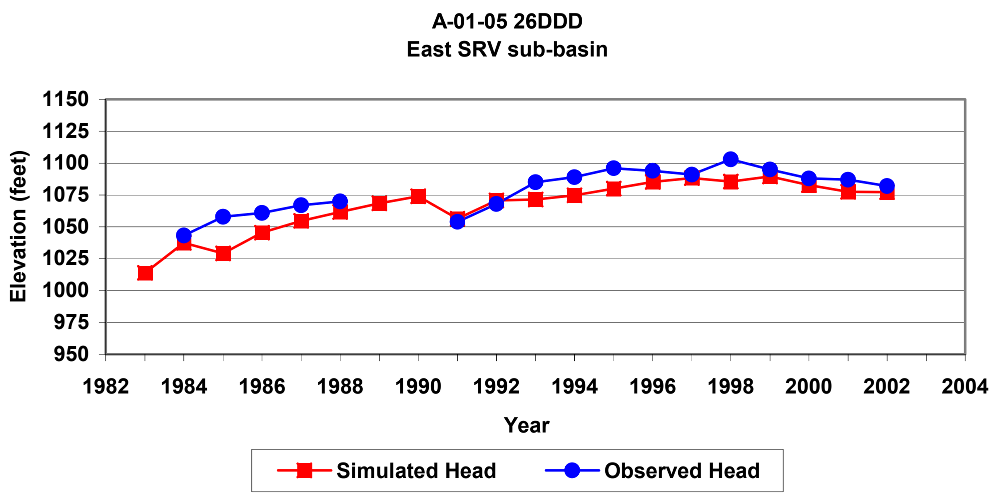


Figure 8b. Scatter plot of model-wide weighted residual vs. weighted observed heads



Summary statistics of simulated heads vs. observed heads describe the model results at the end of a simulation. Hydrographs that display observed water levels vs. simulated water levels through time can be used to compare the model response through time. Figure 9 presents selected hydrographs from the East and West SRV sub-basins that show the SRV model response during the calibration period. The hydrographs show that the model simulation is generally able to replicate the regional aquifers response to the stresses applied during the transient model period.

Figure 9. Selected hydrographs from the SRV model, 1983-2002.



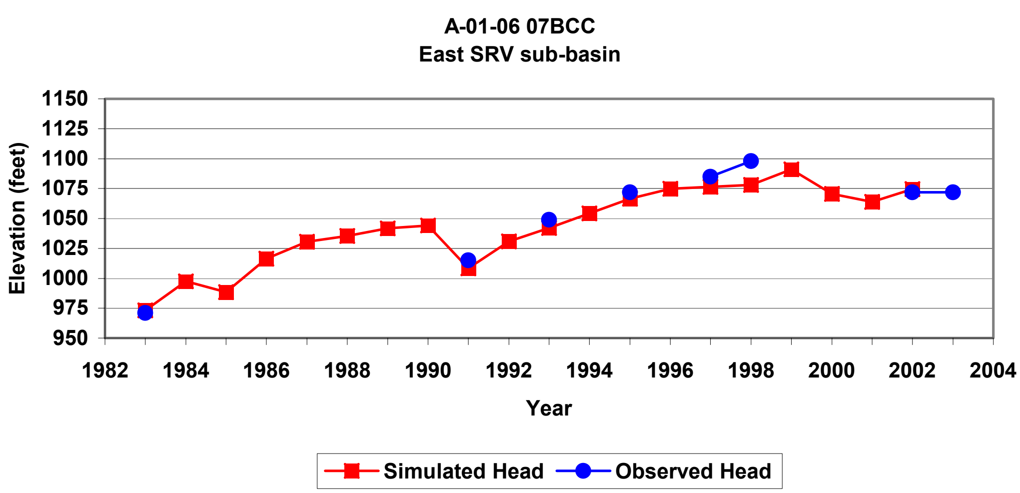
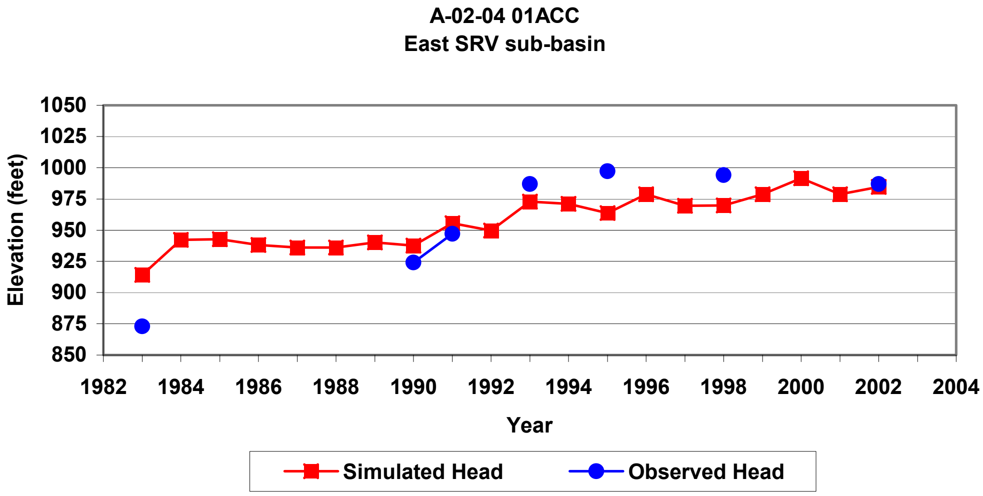
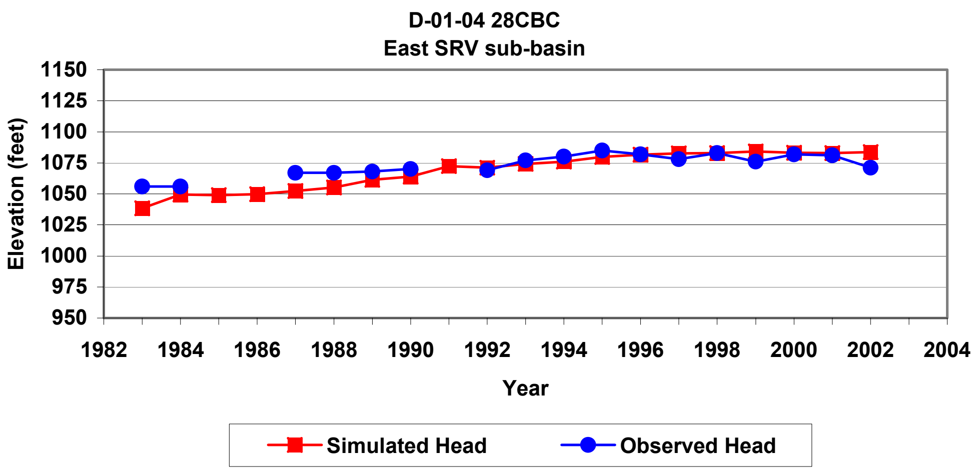


Figure 9. Selected hydrographs from the SRV Model, 1983-2002 (Continued)





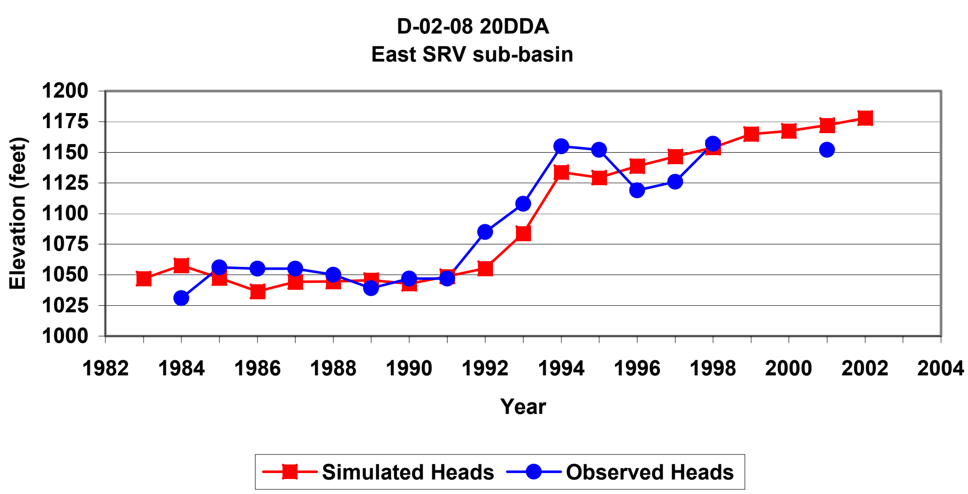
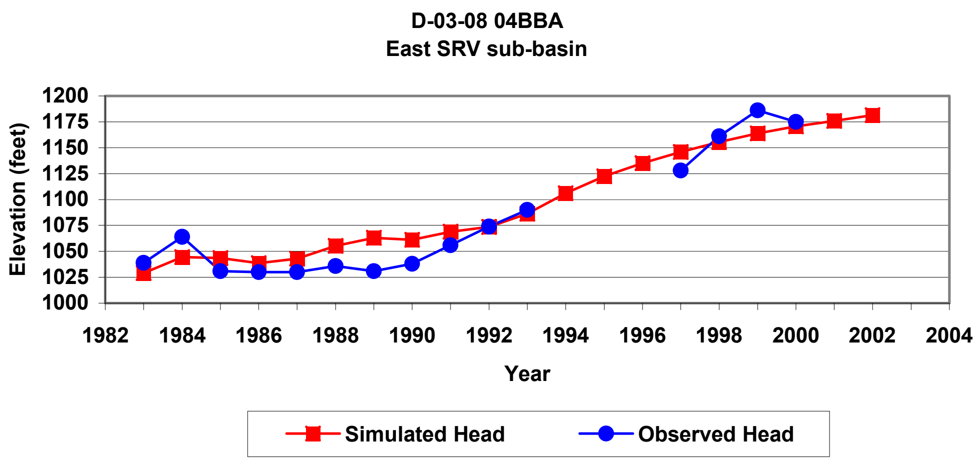
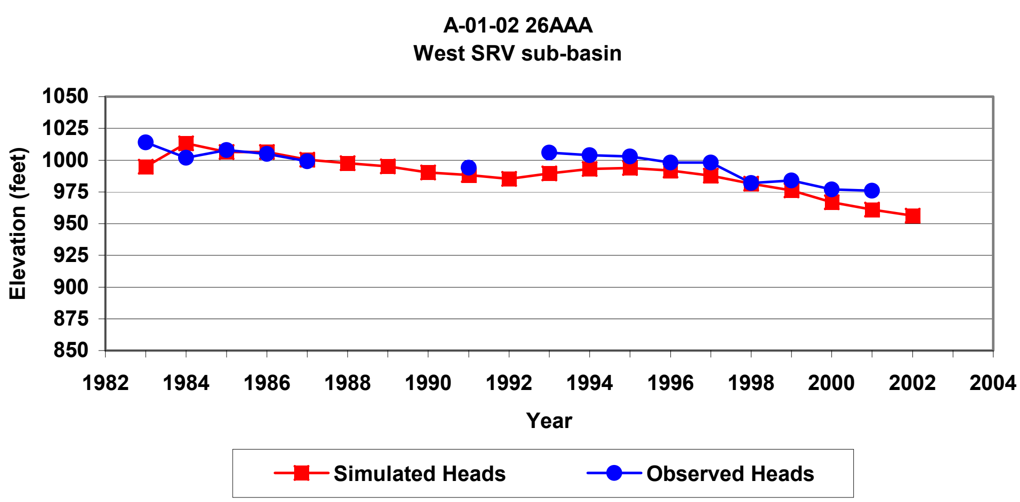


Figure 9. Selected hydrographs from the SRV Model, 1983-2002 (continued).





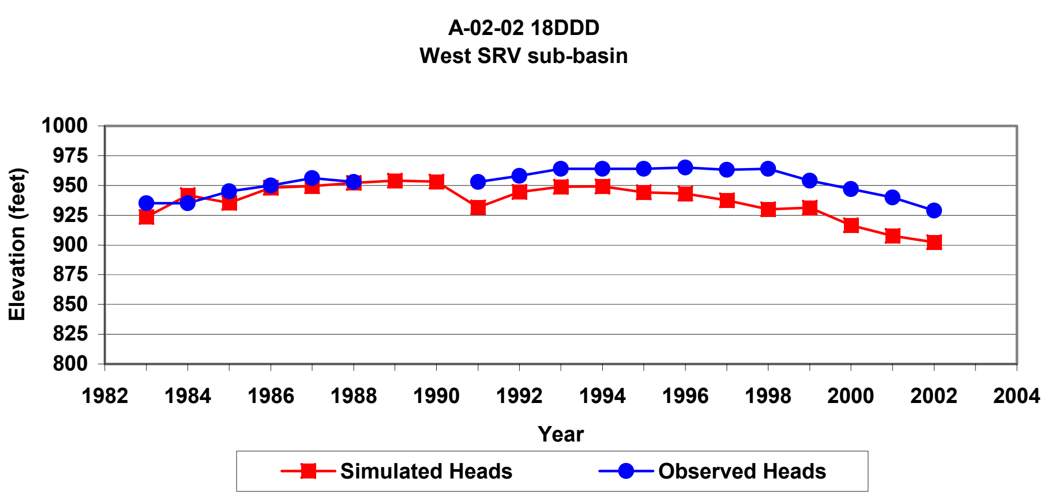
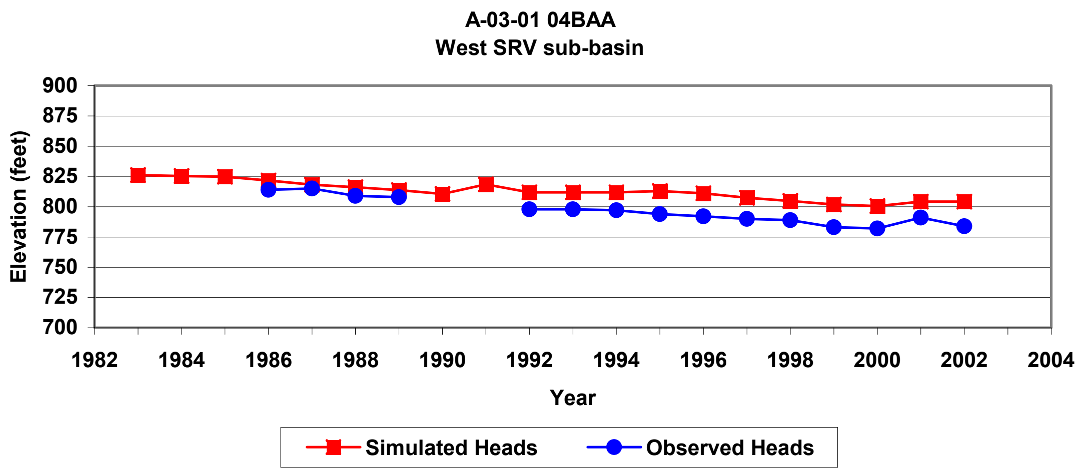
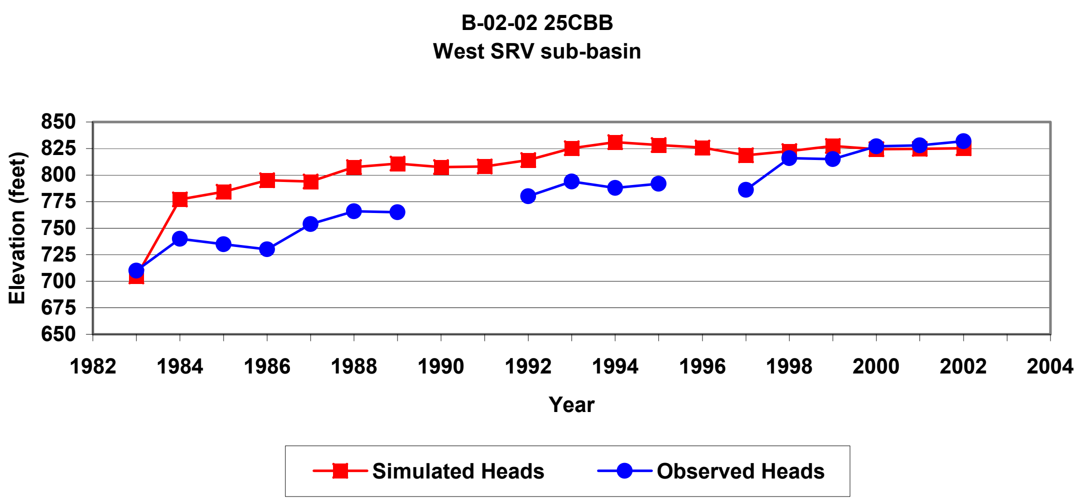
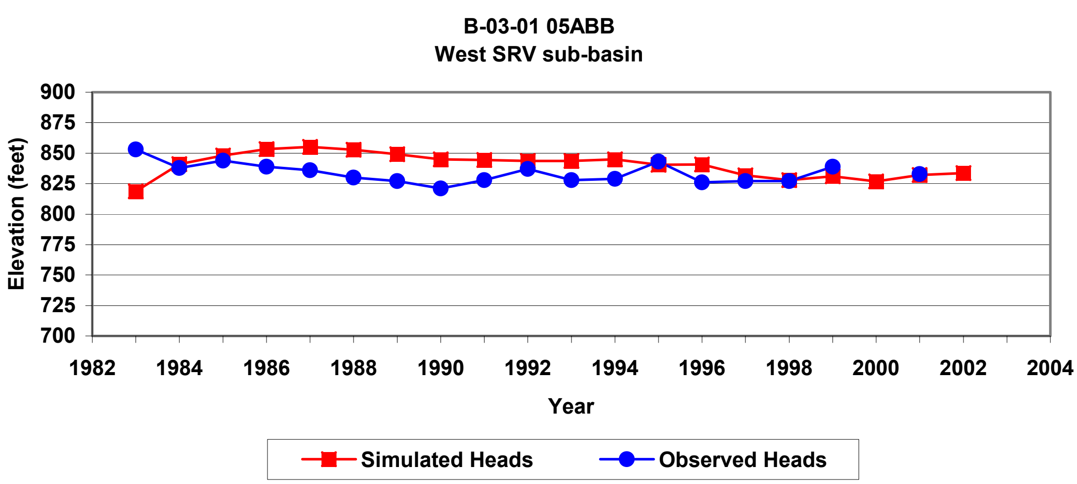


Figure 9. Selected hydrographs from the SRV Model, 1983-2002 (Continued)







Water Budget Results:

The updated SRV model simulated water budget for 1983 to 2002 is presented in Table 3. Overall, the annual model inflows and outflows are within ±6% of the conceptual annual water budget inflows and out flows for the transient period of 1983 to 2002. Conceptual estimates of flood flow recharge along the Salt and Gila Rivers were decreased during the model calibration. Initial flood flow recharge estimates for the upper reaches of the Gila River caused the river to flow over several stress periods in areas where there is no perennial flow. During the model recalibration, the initial recharge values were decreased until the river ceased flowing, except during the flood years. This resulted in a much improved over all calibration in the southeastern portions of the model.

The simulated cumulative model water budget presented in Table 3 shows a net increase in storage during the modeled period. However, zone budget analysis of the simulated water budget, which examines the East SRV and West SRV sub-basin water budgets separately, indicates that there is a net increase of storage in the East SRV sub-basin and a net loss of storage in the West SRV sub-basin. Simulated water budgets for the sub-basins presented in Table 4 indicate that the East SRV sub-basin experienced a net increase in storage of about 3,010,000 acre-feet and the West SRV experienced a net loss of storage of about 1,269,000 acre-feet. The zone budget results are within ±3% of the simulated cumulative water budget. Although in theory the two budgets should agree, there are usually small differences between them because the zone budget volumes are calculated based on a rate (Ft^3/Day in the SRV model) per model time step. The SRV model uses 12 time steps and the storage rates can change between time steps within a stress period. The zone budget values were calculated based on storage changes during the last time step prorated over the entire stress period. This probably accounts for the discrepancy between the cumulative model budget and the zone budget results. The zone budget results generally agree with observed water levels (Figures 1 and 2), which indicate that water levels are generally rising in the East SRV and declining in the West SRV sub-basin from 1983 to the present.

SUMMARY

Several modifications have been made to ADWR's SRV groundwater flow model since the last model update in 1996. These modifications include conversion to MODFLOW-2000, extension of the calibration period to 20 years (1983-2002), addition of the Stream-Flow Routing Package, modification of the distribution of the historic Salt and Gila River recharge, and modification to some hydraulic conductivity inputs.

It is difficult to quantitatively analyze the improvement of the current calibration over the initial 1991 calibration. The ability access, analyze, and display output from MODFLOW has improved greatly since the initial SRV model calibration in 1991. For example, the statistical analysis of the initial model's error involved comparing the final simulated heads to heads assigned to model cell-centers from a hand-contoured water table map. These model heads were manually assigned to cells by overlaying a copy of the model grid on a hand-contoured water level elevation map and interpolating from the nearest water level contour elevation line to a cell-center.

Table 3. SRV model simulated water budget 1983 – 2002 (all units are in acre-feet).

Year	Model Simulated Recharge	Stream Infiltration	Well Specified Underflow	Constant Head Underflow	Total Water Budget Inflows		Constant Head Underflow Out	Pumpage Out of Model	ET	Total Water Budget Outflows	Water Budget Annual Change In Storage	Water Budget Cumulative Change In Storage
1983	1,606,797	66,845	33,349	13,398	1,720,388		5,229	812,808	47,172	865,208	855,179	855,179
1984	1,041,104	85,933	33,349	12,273	1,172,659		8,070	1,339,414	48,539	1,396,023	-223,364	631,815
1985	1,193,716	82,274	33,348	11,938	1,321,275		8,870	1,023,422	47,654	1,079,946	241,329	873,144
1986	936,343	86,349	33,342	11,700	1,067,734		9,216	992,550	45,542	1,047,308	20,426	893,569
1987	926,951	89,465	33,342	12,048	1,061,805		9,105	941,451	42,841	993,397	68,408	961,978
1988	934,673	91,850	33,342	12,164	1,072,029		9,002	998,294	39,931	1,047,227	24,802	986,780
1989	849,865	93,675	34,342	12,388	990,269		8,675	1,048,963	36,934	1,094,572	-104,303	880,781
1990	880,033	94,820	34,342	12,833	1,022,028		8,398	1,181,014	34,329	1,223,741	-201,713	677,372
1991	948,918	95,481	34,342	13,008	1,091,748		8,303	953,765	31,512	993,580	98,168	773,844
1992	1,113,673	88,415	34,342	13,029	1,249,458		8,796	642,164	31,230	682,190	567,268	1,341,112
1993	1,701,544	69,614	34,342	12,919	1,818,419		8,996	698,505	39,651	747,152	1,071,267	2,412,379
1994	876,156	80,908	35,431	13,913	1,006,407		7,913	912,124	40,966	961,003	45,404	2,457,783
1995	983,275	85,915	34,342	13,673	1,117,204		8,221	818,839	37,854	864,913	252,291	2,710,074
1996	756,805	88,689	34,342	13,431	893,267		8,042	999,343	35,379	1,042,764	-149,498	2,560,577
1997	711,237	92,993	34,275	13,034	851,539		8,073	930,327	32,788	971,188	-119,650	2,440,927
1998	731,060	94,031	34,261	12,230	871,583		8,436	760,976	31,145	800,557	71,026	2,511,952
1999	654,584	95,178	34,261	11,981	796,004		8,710	1,001,798	29,588	1,040,096	-244,092	2,267,860
2000	695,350	98,093	34,261	12,907	840,610		8,017	996,752	26,399	1,031,168	-190,558	2,077,302
2001	665,958	100,054	34,261	12,594	812,868		8,024	847,525	22,966	878,515	-65,647	2,011,655
2002	670,453	100,265	34,261	12,842	817,821		8,556	990,964	20,437	1,019,957	-202,135	1,809,520

Notes:

1) Model simulated recharge includes agricultural, effluent, non-effluent, urban and turf recharge, canal seepage and river flood recharge.
2) Well specified underflow includes boundary underflows and minor recharge from ephemeral streams.
3) Constant head underflow includes boundary underflow into the model.
4) Constant head underflow out includes boundary underflow out of the model.
5) Pumpage out of the model includes Indian, agricultural, domestic, industrial, and municipal pumpage, plus specified boundary underflow out of the model.
6) Discrepancies between the cumulative change in storage in Table 3 and the change in storage in the MODFLOW list file are due to

differences in the simulated inflows and outflows (In – Out in the Listing file).

Table 4. Simulated change in storage for the East and West SRV sub-basins.

Year	West SRV Annual Change Net (ac-ft)	Cumulative	East SRV Annual Change Net (ac-ft)	Cumulative
1983	377,679	377,679	441,722	441,722
1984	-125,136	252,543	-82,569	359,153
1985	20,286	272,829	218,071	577,223
1986	-99,666	173,164	123,770	700,994
1987	-44,949	128,215	115,425	816,418
1988	-61,160	67,055	86,198	902,616
1989	-115,234	-48,178	9,200	911,816
1990	-133,913	-182,091	-70,327	841,489
1991	-43,500	-225,591	137,909	979,398
1992	94,297	-131,294	464,603	1,444,000
1993	238,106	106,812	801,126	2,245,127
1994	-92,806	14,005	143,126	2,388,253
1995	-63,517	-49,511	313,366	2,701,619
1996	-194,471	-243,983	44,938	2,746,557
1997	-196,532	-440,515	75,883	2,822,440
1998	-77,617	-518,132	145,554	2,967,994
1999	-209,258	-727,390	-35,461	2,932,533
2000	-201,924	-929,314	12,410	2,944,942
2001	-141,059	-1,070,373	72,580	3,017,522
2002	-198,813	-1,269,186	-7,072	3,010,450

The current MODFLOW software has the ability of assigning observed water levels as observation points, which can then be compared to simulated heads that are interpolated to the location of the observation point. MODFLOW then calculates the difference between the simulated and observed head (the residual) and provides a basic statistical analysis of the residuals. The observed points can also be weighted based on their relative accuracy so that more accurate observation points will affect the statistical results more than less accurate points.

Despite the difference in how the statistical analysis for the two models was conducted, a general comparison between the two models does indicate that the current calibration is a substantial improvement over the initial calibration. Table 5 presents a comparison of the MAE and standard deviation for layers 1, 2, and 3 of each model calibration. Based on a comparison of the statistics for the two model calibrations it would appear that the modifications to the SRV model have improved the overall model calibration, yielding a model that is better able to replicate the past aquifer response to regional stresses.

Table 5. SRV model calibration statistics, 1991 calibration vs. 2002 calibration.

Layer	1991 MAE	2002 MAE	1991 Std Dev	2002 Std Dev
1	14.4	14.3	12.7	15.7
2	20.4	12.4	19.5	17.8
3	22.1	11.1	22.2	14.0

Planned Future Updates to the SRV Model

The SRV model is currently undergoing a major update, which will include:

1. Revision to the model hydrogeology. This includes incorporating recent well log and aquifer test data. Where appropriate, model layer elevations will be adjusted. The new aquifer test data will be used to further refine the distribution of model simulated hydraulic conductivities.

2. New cell size. The current model cell size of one mile by one mile will be replaced with a grid of cells that are one-half mile by one-half mile. The finer model grid will allow for better resolution for assigning model pumpage and recharge. Simulation of stream-aquifer interaction and model boundary conditions will also be improved.

3. New boundary conditions. Several head-dependent model boundaries, such as the Maricopa-Stanfield outflow boundary into the Pinal AMA, will be converted from specified fluxes to time-variant constant head boundaries. Allowing these boundaries to change with respect to heads inside the model area will should improve the model ability to simulate actual aquifer responses along these boundaries.

4. A long-term calibration from 1900 to present. Extending the model calibration back to 1900 will provide a longer calibration period, which will benefit the overall model calibration.

5. Addition of the Subsidence package to simulate historic aquifer compaction.

6. Eventual combination of the SRV and Pinal AMA models into one model. Combining the two models will eliminate the artificial boundary that currently exists between the two models.

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